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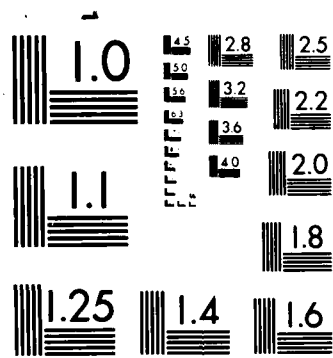
PERFORMANCE EVALUATION OF MIL-L-2104D ENGINE OILS IN
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PERFORMANCE EVALUATION OF MIL-L-2104D ENGINE OILS IN TRANSMISSION FRICTION BENCH TESTS

INTERIM REPORT
BFLRF No. 222

By

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Southwest Research Institute
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<p>The objective of this work was to investigate the capability of 15W-40 lubricants to meet the frictional requirements of military powershift and automatic transmissions; and, if required, provide a procedure for selecting acceptable lubricants for application under the MIL-L-2104D specification. A variety of lubricants were evaluated during this test program. The oils included DDA C-3 pass and fail reference oils, five MIL-L-2104D oils, and two special experimental oils. Four of the nine test lubricants were 15W-40 oils. The test lubricants were evaluated for torque, sliptime, and disc/plate wear using a modified DDA C-3 friction test. Various bronze friction materials used extensively in Allison combat/tactical automatic and powershift transmissions were tested under varying operating conditions.</p> <p>Data compiled from this work and from field data have shown that the 15W-40 lubricants will meet the frictional requirements of the DDA combat/tactical automatic and powershift transmissions.</p>					
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FOREWORD

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I. BACKGROUND

For years powershift transmissions use in Army combat, tactical, and construction equipment have been designed to operate with MIL-L-2104 straight grade engine oils. The U.S. Army, in recognition of the use of engine oils in wet-friction applications, included the C-3 (1)* and TO-2 (2) friction retention tests in oil specification MIL-L-46167 in 1974. When oil specification MIL-L-2104 was revised to include multiviscosity grade oils in 1983, the C-3 and TO-2 friction retention tests were included.

A. CCE/MHE Applications

In the early 1970's, the U.S. Army recognized the need for constant modernization but was confronted with decreasing research and development budgets. As a result, the Army adopted a policy of procuring construction equipment (CCE) and material-handling equipment (MHE) from commercial sources.(3) Today the majority of CCE and MHE utilized by the Army is of the commercial or modified commercial type. Although obvious advantages exist for this policy, certain problems required resolution to make the CCE and MHE program successful. The fluids used in the various multipurpose hydraulic systems are considered as components of the total system and are usually provided under commercial proprietary fluid specifications.(4) Using these various manufacturers' fluid specifications over a period of time would obviously lead to a proliferation of proprietary hydraulic fluids, creating a logistic burden to the supply system. However, using fluids unauthorized by the equipment manufacturers could invalidate the equipment warranty. Also, many manufacturers are reluctant to permit the use of other than specified fluids in their equipment.

Thus, the U.S. Army conducted several programs to determine the performance of Army engine oils in various CCE/MHE hydraulic, powershift, and multipurpose power transmission systems.(4-12) The results from this work have shown that the limiting factors of the Army engine oils as hydraulic, powershift, and multipurpose power transmission fluids appear to be (1) wet-brake chatter noise in multipurpose power transmissions, (2) hydraulic pump wear problems with some piston pumps using MIL-L-46167 Arctic engine oils at temperatures higher than expected in Arctic conditions, and (3) possible copper corrosion/reactivity. The prime area of concern is the wet-brake chatter noise.

* Underscored numbers in parentheses refer to the list of references at the end of this report.

B. Combat and Tactical Automatic/Powershift Transmissions

The majority of the combat and tactical automatic and powershift transmissions used in the Army today are manufactured by Detroit Diesel Allison (DDA). The new transmissions have had and will continue to have an increased demand on fluid performance due to the emphasis being placed on tactical mobility of new equipment. These transmissions and drives have a common sump for the hydraulic system, torque converters, gears, range clutches, wet-brakes (clutch type), vane and/or hydrostatic pumps and do not fit into the traditional and proposed ASTM hydraulic fluid categories of:

1. Hydraulic oils with improved antirust and antioxidation properties and are defined by viscosity
2. Hydraulic oils with improved antiwear properties and are defined by viscosity
3. Passenger car/light truck automatic transmission fluids (such as Dexron.-II and Type F)
4. Powershift transmission oils for heavy-duty trucks and construction/off-road equipment with friction retention requirements (such as DDA C-3 graphite and Caterpillar TO-2 bronze)
5. Multipurpose power transmission oils commonly used in farm tractors and front loader/backhoes (these fluids operate in hydraulic systems, hydrostatic and vane pumps, transmissions, wet-brakes, wet PTO's, and final drives; such as John Deere J20A, J.I. Case TCH 145, International Harvester B-6, Massey-Ferguson M1139, Oliver/White S-3727).

The combat/tactical automatic and powershift transmissions that develop high frictional energies use primarily bronze friction material and fall between categories 4 and 5. These transmission components were designed to operate with MIL-L-2104 Tactical Service Engine oils and MIL-L-21260 Preservative Engine oils, grade 10W or 30 at normal ambient temperatures. They use MIL-L-46167 Arctic Engine oils, grade 0W-20 at ambient temperatures to below -15°F (-25°C) (TABLE 1). In keeping with the Army directive to use single lubricants for multipurpose uses, a MIL-L-2104D, grade 15W-40 lubricant was introduced into the Army system in 1983.

TABLE 1. DDA Authorized Transmission Lubricants

<u>Transmission</u>	<u>Application</u>	<u>Approved Oils</u>	<u>Ambient Temperature Range</u>
X1100-3B	M1 Tank	MIL-L-2104, Grade 30 MIL-L-46167	Above +10°F (-12°C) +20°F to -70°F (-7° to -57°C)
		MIL-L-21260, Grade 30	Break-In, Shipping, Storage
CD-850-6A1, -6A, -5, -4B	M60 Series, M48 Series	MIL-L-2104, Grade 10 MIL-L-46167	Above -10°F (-23°C) Below 0°F to -65°F (-18° to -54°C)
	Tanks	MIL-L-21260, Grade 10	Break-In, Shipping, Storage
XT 1410-4	M88A1	MIL-L-2104, Grade 10	Above -10°F (-23°C) -10°F to -65°F (-23°C to -54°C)
		MIL-L-21260, Grade 10	Break-In, Shipping, Storage
XTG 411-2A	M109 Series, M110 Series,	MIL-L-2104, Grade 10	Above -10°F (-23°C) Below 0° to -65°F (-18° to -54°C)
	M578	MIL-L-21260, Grade 10	Break-In, Shipping, Storage
TX 100-1	M113 Family	MIL-L-2104, Grade 10 MIL-L-46167	Above -10°F (-23°C) Below 0° to -65°F (-18° to -54°C)
	M578	MIL-L-21260, Grade 10	Break-In, Shipping, Storage
X200-4	M730A1E1	MIL-L-2104, Grade 10 MIL-L-46167	Above -10°F (-23°C) Below 0° to -65°F (-18° to -54°C)
		MIL-L-21260, Grade 10	Shipping and Storage
X300-4B	MCV 80	OMD 75 (10W-30) OMD 30 (5W-20)	Above 0°F (-18°C) +5°F to -25°F (-15° to -32°C)
		MIL-L-2104C, Grade 30 MIL-L-2104C, Grade 10	Above +32°F (0°C) +40°F to -10°F (4° to -23°C)
		MIL-L-46167	Below 0°F to -65°F (-18° to -54°C)
		MIL-L-21260, Grade 10	Shipping and Storage
		MIL-L-2104C, Grade 10 MIL-L-46167	Above -10°F (-23°C) +10°F to -65°F (-12° to -54°C)
Commercial Transmissions			
MT-Series	M939	Dexron® or Dexron®-II	Above -30°F (-34°C)
HT-Series	M915, HEMTT	Hydraulic Transmission Fluid Type C-3, Grade 10 MIL-L-21260	Above -10°F (-23°C)

II. INTRODUCTION

With the introduction of the new MIL-L-2104D specification, Detroit Diesel Allison (DDA) expressed concern that multiviscosity grade 15W-40 lubricants may not be adequate for their X1100, X300, X200, XTG-411, XT-1410, TX-100, and C-850 automatic and powershift transmissions with hydrostatic and clutch steering (Fig. 1). DDA contended that the major problem is a combination of higher energy levels and the necessary use of bronze friction materials to meet those higher energy levels. This concern was based on results of an in-house three-energy level test procedure using bronze friction material in which two 15W-40 lubricants had failed at energy levels lower than DDA desired. DDA also expressed some concern about the effects of viscometric characteristics on the functional controls of the transmission. These problems occurred even though the 15W-40 lubricants had met the DDA C-3 (graphitic friction material) and Caterpillar TO-2 (bronze friction material) fluid specifications for powershift transmissions. This failure to predict the problem could mean that most current transmission fluid test procedures may be inadequate for tactical military powershift transmission applications. Therefore, a program was developed to resolve the use of MIL-L-2104D, grade 15W-40 lubricants in DDA military transmissions.

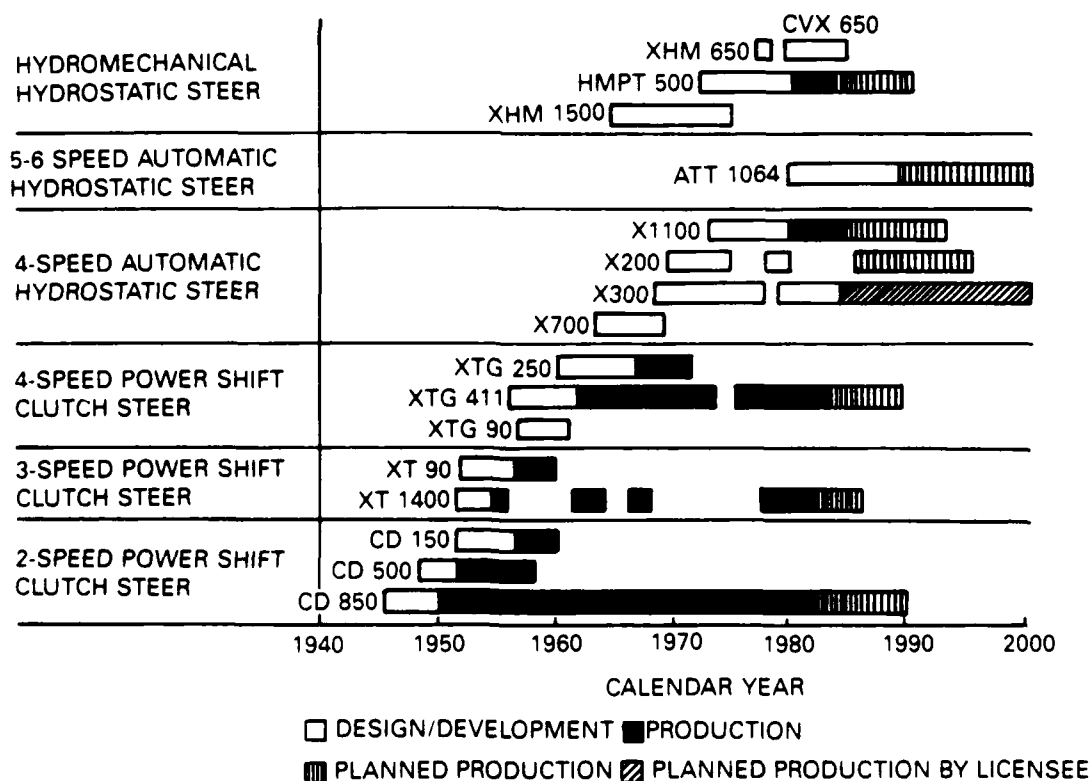


Figure 1. Military transmission and steering chronology

III. OBJECTIVE

The objective of this work was to investigate the capability of 15W-40 lubricants to meet the frictional requirements of military powershift and automatic transmissions; and, if required, provide a procedure for selecting acceptable lubricants for application under the MIL-L-2104D specification.

IV. TEST DETAILS

A. Modified C-3 Bronze Friction Test Procedure

The SAE No. 2 friction machine was used in this test program because it provided versatility at a reasonable cost and is used extensively in the automotive and heavy equipment industry. The DDA C-3 Friction Retention specifications (1) were used when possible, and the test results are reported in three performance areas: (1) minimum torque at 0.2 sec sliptime at 5500 cycles = 75 lb-ft minimum, (2) maximum sliptime at 5500 cycles = 0.85 sec maximum, and (3) difference in torque at 0.2 sec sliptime between 1500 and 5500 cycles = 30 lb-ft.

Several modifications were made to the C-3 friction test. The major modification was the changing from graphite friction material to bronze friction material. Three bronze friction materials used extensively in Allison combat/tactical automatic and powershift military transmissions were used. Another change was oil temperature because of the increased operational temperature expected in military combat/tactical transmissions. The temperatures were increased from the standard 235°F (113°C) to 250°F (121°C), 275°F (135°C), 300°F (149°C), and 325°F (163°C). Energy level was another modification. Tests were performed at the standard 13,800 ft-lb of kinetic flywheel energy and then increased to 15,500 ft-lb of kinetic flywheel energy. In addition, all bronze friction discs and steel reaction plates were inspected and measured at six points for wear and glazing. The surfaces of some bronze friction discs were inspected with the electron microscope interfaced to the XRF Analyzer. Also, the effects of apply pressure were investigated. The majority of the work was conducted with the standard C-3 arrangement of a single disc and two steel reaction plates at 60 and 120 psi apply pressures. However, some work was performed with a multidisc arrangement of four friction discs and five steel reaction plates at 60 psi.

It had been planned to increase the apply pressure to 160 psi and to add a 23,800 ft-lb kinetic energy flywheel to simulate the higher energies and pressures developed in some combat/tactical transmissions. However, this phase could not be accomplished at this time because the SAE No. 2 machine had to be modified to achieve the higher apply pressures.

B. Test Lubricants

A variety of lubricants were evaluated during this test program. The oils included DDA C-3 reference oils, MIL-L-2104D oils, and special experimental oils. A description of each test oil is presented in TABLE 2, and the properties for each test oil are presented in TABLE 3. Lubricant No. 7, while not a qualified product, was used in developing the requirements for MIL-L-2104D. Lubricant No. 8 was the same formulation as lubricant No. 7 except that the VI improver was omitted. This special oil was used to determine if the VI improver additive affected wet friction performance of an oil. The following oil formulation technologies were represented: Mg/Zn, Ca (major)-Mg/Zn, Mg (major)-Ca/Zn. Lubricant Nos. 3, 5, 6, and 9 were used by DDA in examining the suitability of MIL-L-2104D oils for use in CD-850 transmissions.⁽¹³⁾

TABLE 2. Test Lubricants

<u>Lube No.</u>	<u>Grade</u>	<u>Description</u>
1	--	DDA C-3 Pass Reference Oil
2	--	DDA C-3 Fail Reference Oil
3*	10W	MIL-L-2104D Army Reference Oil
4	30	MIL-L-2104D Army Reference Oil
5*	15W-40	MIL-L-2104D Qualified Product
6*	15W-40	MIL-L-2104D Army Reference Oil
7	15W-40	Experimental Oil
8	30	Lube No. 7 Without VI Improver
9*	15W-40	MIL-L-2104D Qualified Product

* Lubricant qualified for the DDA CD-850 and XT-1410 transmission by DDA/TACOM.

TABLE 3. Test Lubricant Properties

Lube No. Vis. Grade	3 <u>10W</u>	4 <u>30</u>	5 <u>15W-40</u>	6 <u>15W-40</u>	7 <u>15W-40</u>	8 <u>30</u>	9 <u>15W-40</u>
K. Vis., at 40°C, cSt	39.95	95.82	107.47	99.06	113.20	110.03	103.27
K. Vis., at 100°C, cSt	6.25	11.08	13.66	13.31	14.85	11.95	13.59
VI	103	101	126	133	135	97	131
TAN	2.5	2.6	3.0	2.6	1.9	1.8	3.1
TBN (D 664)	7.3	7.4	7.0	5.4	8.2	8.6	8.8
Sulfated Ash, wt%	0.91	0.91	0.91	1.09	1.03	0.91	0.79
Elements, wt%							
Ba	NIL*	NIL	NIL	NIL	NIL	NIL	NIL
Ca	NIL	NIL	NIL	0.15	0.09	0.10	NIL
Mg	0.15	0.15	0.15	0.05	0.13	0.10	0.12
Zn	0.13	0.13	0.13	0.16	0.12	0.12	0.16
P	0.12	0.12	0.11	0.14	0.12	0.11	0.13
S	0.46	0.55	0.51	0.55	0.65	0.66	0.52
N	0.062	0.067	0.066	0.048	0.12	0.11	0.075

* NIL = less than 100 PPM

V. DISCUSSION OF RESULTS

DDA uses a variety of bronze friction material in its combat/tactical transmissions (TABLE 4). The SKW-167B and RM-1350 bronze friction materials are used most extensively in the new X-series transmissions. These friction materials were not readily available as a standard item for the SAE No. 2 machine 5.25 in. friction disc because the DDA C-3 friction test uses graphitic friction material. Therefore, the bronze discs had to be manufactured. While waiting for delivery, BFLRF was able to acquire several RM-1349 bronze discs, a previous batch used in TO-2 friction tests and the same material used in the DDA CD-850 (M-60 tanks) transmission.

TABLE 4. Bronze Clutch/Brake Materials Usage

Clutch/Brake Material	Transmission					
	<u>TX100</u>	<u>XTG-411</u>	<u>XT-1410</u>	<u>CD-850</u>	<u>X200</u>	<u>X1100</u>
GEMPCO-970	X					
SKW-97A		X				
SKW-97J		X				
SKW-145			X		X	
SKW-145E		X	X	X		
RM-1349		X	X	X		
SKW-166B					X	
SKW-167B					X	X
RM-1350					X	X

A. RM-1349 Bronze Friction Material

The initial baseline work was conducted with the RM-1349 material using the C-3 friction retention test standard operating conditions, and these test results can be seen in TABLE 5. Lubricant Nos. 1, 2, and 4 through 9 did not meet the standard C-3 friction retention test requirements when using the RM-1349 bronze friction material. The C-3 requirements were met by Lubricant No. 3 (grade 10W). Lubricant No. 3 did, however, start the test out of specification but completed the test within specification as can be seen in Fig. 2. Even Lubricant No. 1, the C-3 pass reference oil, did not meet the C-3

**TABLE 5. Summary of Modified C-3 Bronze Friction Test Results
With RM-1349**

Lubricant Description		Modified* C-3 Bronze Friction Test				
		5500 Cycle ^a	Slip- Time ^b ,	Torque ^c	Wear**, in. (cm)	
Code	Grade	Torque, 75 min	0.85 max	Diff, 30 max	Steel	Bronze
1*	--	62	1.20	+4	0.0004 (0.1016)	0.0011 (0.2794)
2	--	72	0.95	+8	0.0002 (0.0508)	0.0026 (0.6604)
3	10W	83	0.85	+15	0.0004 (0.1016)	0.0034 (0.8636)
3	10W	73	1.00	+1	0.0010 (0.0254)	0.0025 (0.6350)
4	30	78	0.90	+13	0.0003 (0.0762)	0.0025 (0.6350)
5	15W-40	74	0.97	+11	0.0002 (0.0508)	0.0046 (1.1684)
6	15W-40	67	1.01	+8	0.0005 (0.1270)	0.0018 (0.4572)
7***	15W-40	67	1.08	+5	0.0007 (0.1778)	0.0128 ⁺ (3.2512)
7	15W-40	70	0.95	+6	0.0009 (0.2286)	0.0034 (0.8636)
7	15W-40	68	1.00	+8	0.0012 (0.3048)	0.0025 (0.6350)
7	15W-40	59	1.08	+3	0.0008 (0.2032)	0.0030 (0.7620)
8	Lube No. 7 Less VII	70	0.96	+14	0.0011 (0.2794)	0.0041 (1.0414)
<u>Multidisc Pack</u>						
3	10W	200	1.47	+20	0.0054 (1.3716)	0.0045 (1.1430)
7	15W-40	155	0.45	+12	0.0044 (1.1176)	0.0040 (1.0160)

* Standard Allison C-3 requires the following:

^a Minimum torque at 0.2-sec sliptime at 5500 cycles = 75 lb-ft.

^b Maximum sliptime at 5500 cycles = 0.85 sec.

^c Difference in torque at 0.2-sec sliptime between 1500 and 5500 cycles = 30 lb-ft max.

** Caterpillar TO-2 max. average wear: 2-steel plates = 0.004 in. (0.1016 cm)
1-bronze plate = 0.010 in. (2.54 cm)

*** Original lubricant used for MIL-L-2104D specification work.

+ Lube No. 7, 15W-40 had high wear that could not be repeated.

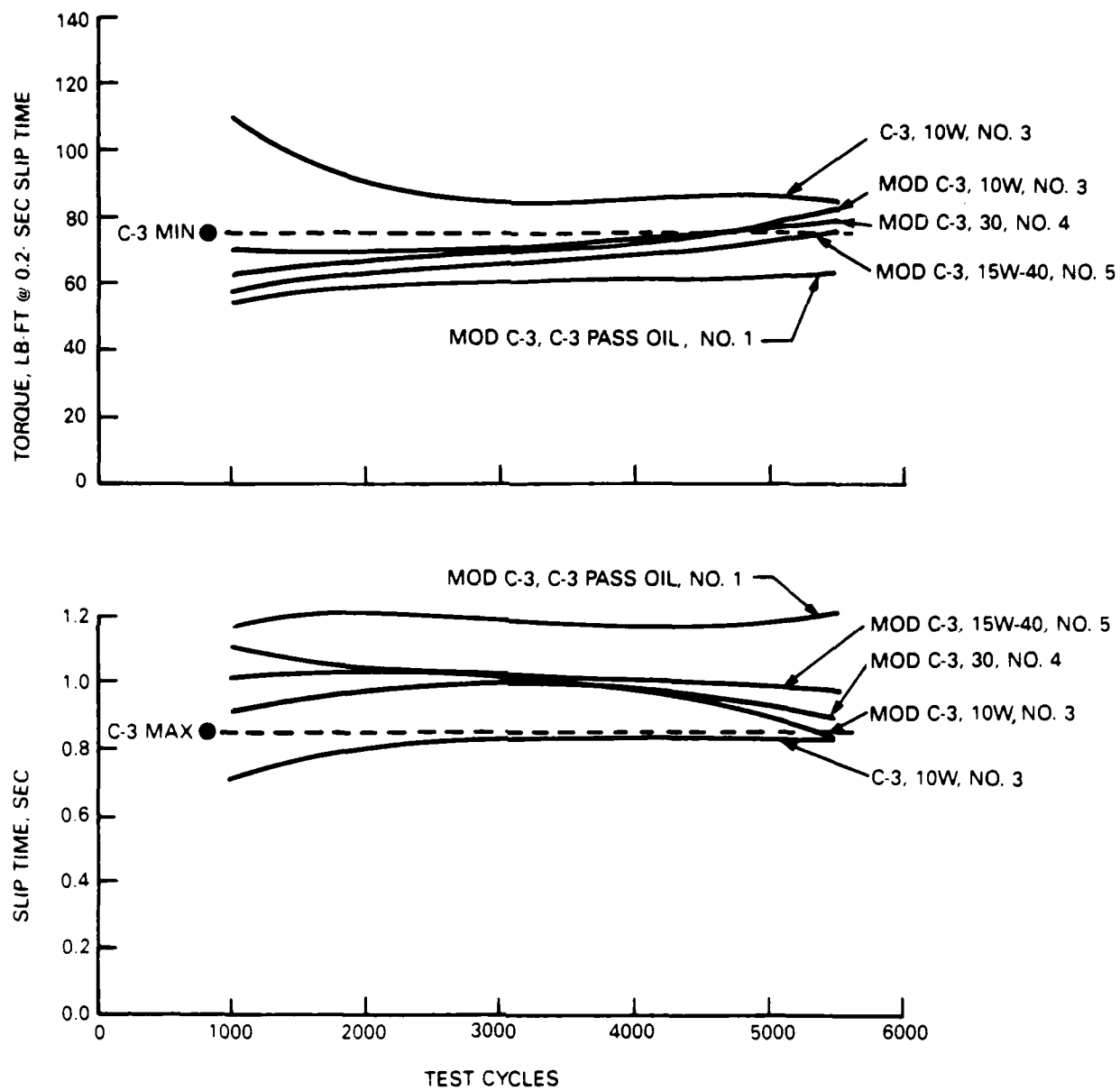


Figure 2. Standard C-3 versus modified C-3 bronze with RM-1349

specification. No difference was observed between the grade 10W, 30, and 15W-40 lubricants torque, sliptime, and wear. When comparing Lubricant No. 7 (with VI improver) to Lubricant No. 8 (without VI improver), no significant difference could be seen (Fig. 3). The RM-1349 bronze friction material generally produced results that increased in torque and decreased in sliptime with increased test cycles. The standard C-3 friction retention test, which uses graphitic material, decreased in torque and increased in sliptime in relation to increased test cycles. Also, some erratic high disc wear was experienced with the RM-1349 bronze material, but could not be reproduced. Also no significant difference could be seen in the torque and sliptime curves. The CD-850 powershift transmission and the DDA three-energy level tests which failed the MIL-L-2104D, grade 15W-40 lubricant used multidisc friction packs. Therefore, it was necessary to establish data with a multidisc friction pack in the modified C-3 bronze friction test, because of a possible synergistic effect from the use of a multidisc friction pack. Tests were conducted with a multidisc friction pack (five steel reaction plates and four RM-1349 bronze friction discs) using the standard C-3 operating conditions. When using the 120-psi apply pressure, as specified, the 235°F (113°C) lubricant test temperature could not be maintained even when using the larger TO-2 cooler. In addition, the load cell could not handle the high torque and malfunctioned. Therefore, the apply pressure was reduced. At 60 psi, the load cell functioned properly and the 235°F (113°C) lubricant temperature could be maintained. Tests were then conducted using Lubricant No. 3 (grade 10W) and Lubricant No. 7 (grade 15W-40). Although Lubricant No. 3 (grade 10W) easily passed the torque area with 30 percent more than the grade 15W-40, it failed C-3 requirement in sliptime (see TABLE 5). Lubricant No. 7 passed the torque and the sliptime part of the C-3 requirements. It should be remembered that the C-3 requirement is established for one disc and two reaction plates. Wear on the individual friction discs and plates was approximately the same as with the standard C-3 arrangement. From this limited testing with a multidisc friction pack, it appears that the grade 15W-40 performs as good or better than the grade 10W lubricant.

The testing with RM-1349 bronze friction material had to be discontinued at this time because the disc supply was exhausted.

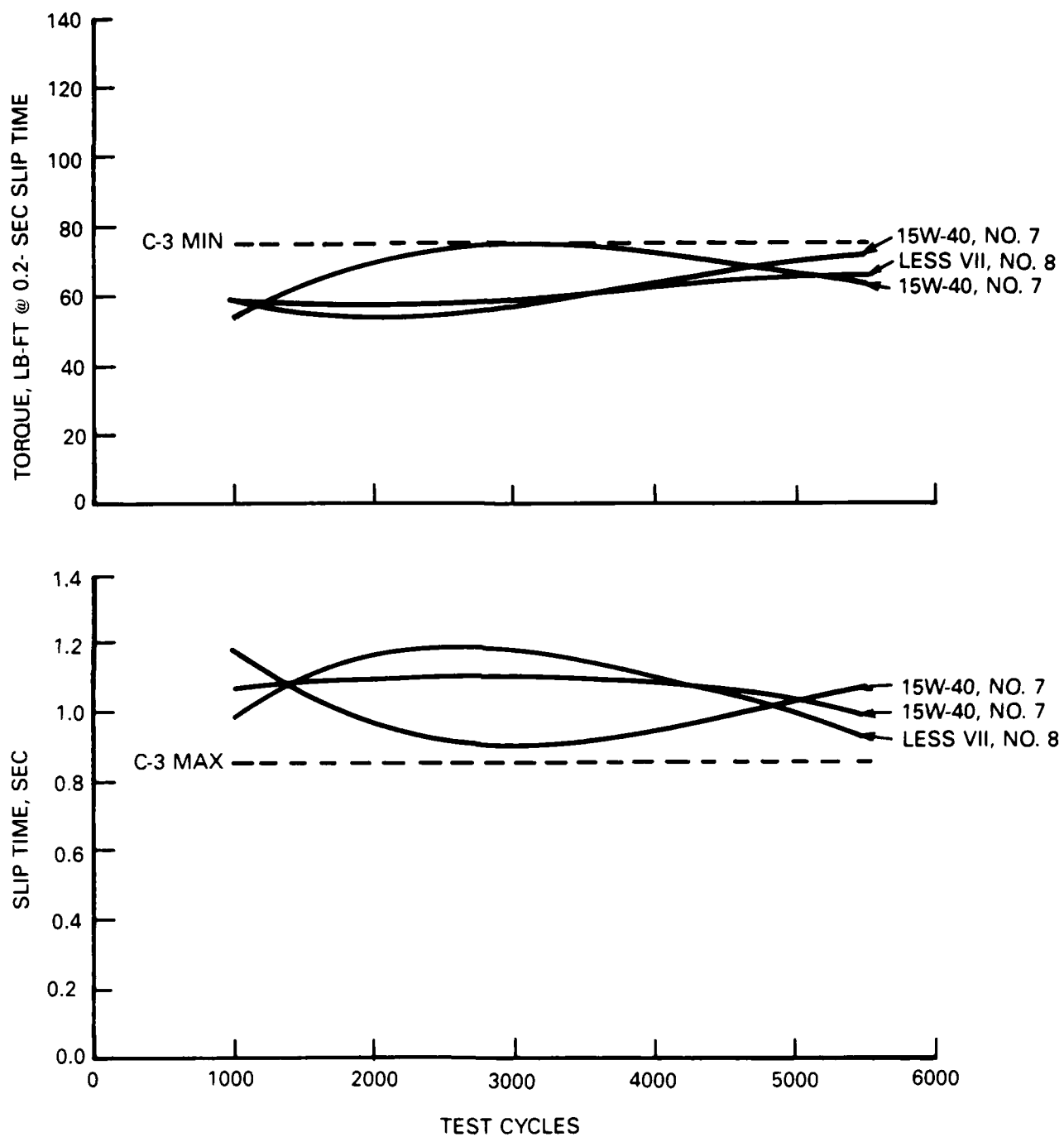


Figure 3. Effect of VI improver using RM-1349 material

B. SKW-167B Bronze Friction Material

The SKW-167B material is the most common bronze friction material in the X200 and X1100 Automatic 4-speed transmission with hydrostatic steering. Also, the bronze material is similar to bronze friction material used in the three-energy level friction test at DDA which failed the two 15W-40 lubricants. Baseline testing was conducted with Lubricant Nos. 1 and 3 through 9. The SKW-167B bronze friction material was used with the C-3 standard operating conditions. When the average of these results in TABLE 6 is compared to the average results of the tests using RM-1349 bronze material disc in TABLE 5, several differences were observed. The SKW-167B bronze material (like the standard C-3 graphite material) decreased in torque and increased in sliptime during the test; whereas, the RM-1349 bronze material increased in torque and decreased in sliptime. Wear of the bronze friction disc and the steel reaction plates decreased slightly when using SKW-167B bronze material. These results indicate that the SKW-167B bronze material has a more slippery surface than the RM-1349 bronze material. In addition, there was no difference with Lubricant No. 7 (with VI improver) and Lubricant No. 8 (without VI improver) (see Fig. 4). The erratic high bronze friction disc wear was observed with Lubricant Nos. 4 and 7, but again it could not be repeated.

Next, the effect of the lubricant temperature on the SKW-167B bronze friction material was investigated. Lubricant temperatures were increased from the standard 235°F (113°C) to 250°F (121°C), 275°F (135°C), 300°F (149°C), and 325°F (163°C) while retaining all other C-3 operating conditions. The results show that as the temperature increased, there was a corresponding increase in sliptime and a decrease in torque (TABLE 7 and Fig. 5). However, there was no apparent effect on wear. Lubricant Nos. 3, 4, and 7 had a test that reached their maximum sliptime and minimum torque at approximately 3000 to 4000 test cycles and then started to decrease in sliptime and increase in torque until the end of the test. This parabolic effect (Fig. 6) is probably due to the detergent/dispersant in the engine oil additive package. The detergent apparently cleans the bronze friction material by restoring the frictional surface and improving the frictional characteristics. In addition, when Lubricant No. 6 (15W-40) temperature was increased to 325°F (163°C), the lubricant foamed out of the test reservoir. An ASTM D 892 foam test indicated the antifoam agent was still present. A new sample of Lubricant No. 6 was obtained, and another friction test was conducted. This test, designed to operate for 5500 cycles, had to be discontinued at 5005 cycles because it could not operate within the 2.5-second stopping time. Another sample of Lubricant No.

**TABLE 6. Summary of Modified C-3 Friction Tests With
SKW-167B Bronze Material**

Lube No.	Grade	Torque, 75 min	Sliptime, 0.85 max	Torque Difference	Wear, in. (cm)	
					Steel	Bronze
1	C-3 Pass	37	1.54	-5	0.0007 (0.1778)	0.0012 (0.3048)
3	10W	56	1.03	0	--	--
4	30	33	1.62	-23	--	--
7	15W-40	30	1.86	-21	--	--
3	10W	35	1.50	-25	0.0009 (0.2286)	0.0006 (0.1524)
4	30	47	1.14	-13	0.0014 (0.3556)	0.0213* (5.4102)
7	15W-40	30	1.80	-18	0.0010 (0.2540)	0.0207* (5.2578)
3	10W	37	1.44	-20	0.0009 (0.2286)	0.0015 (0.3810)
4	30	44	1.38	-4	0.0009 (0.2286)	0.0022 (0.5588)
7	15W-40	38	1.45	-19	0.0008 (0.2032)	0.0017 (0.4318)
3	10W	67	0.89	-5	0.0010 (0.2540)	0.0015 (0.3810)
4	30	48	1.24	-2	0.0022 (0.5588)	0.0019 (0.4826)
7	15W-40	55	1.10	-1	0.0008 (0.2032)	0.0011 (0.2794)
6	15W-40	27	2.18	-22	0.0008 (0.2032)	0.0005 (0.1270)
8	7 With- out VII	35	1.71	-20	0.0006 (0.1524)	0.0009 (0.2286)
8	7 With- out VII	27	2.18	-22	0.0005 (0.1270)	0.0008 (0.2032)
5	15W-40	77	0.86	-25	0.0015 (0.3810)	0.0052 (1.3208)
9	15W-40	45	1.32	-12	0.0011 (0.2794)	0.0018 (0.4572)
5	15W-40	32	1.75	-22	0.0008 (0.2032)	0.0005 (0.1270)

* Lube No. 4, Grade 30 and Lube No. 7, grade 15W-40 had erratic high wear that could not be repeated.

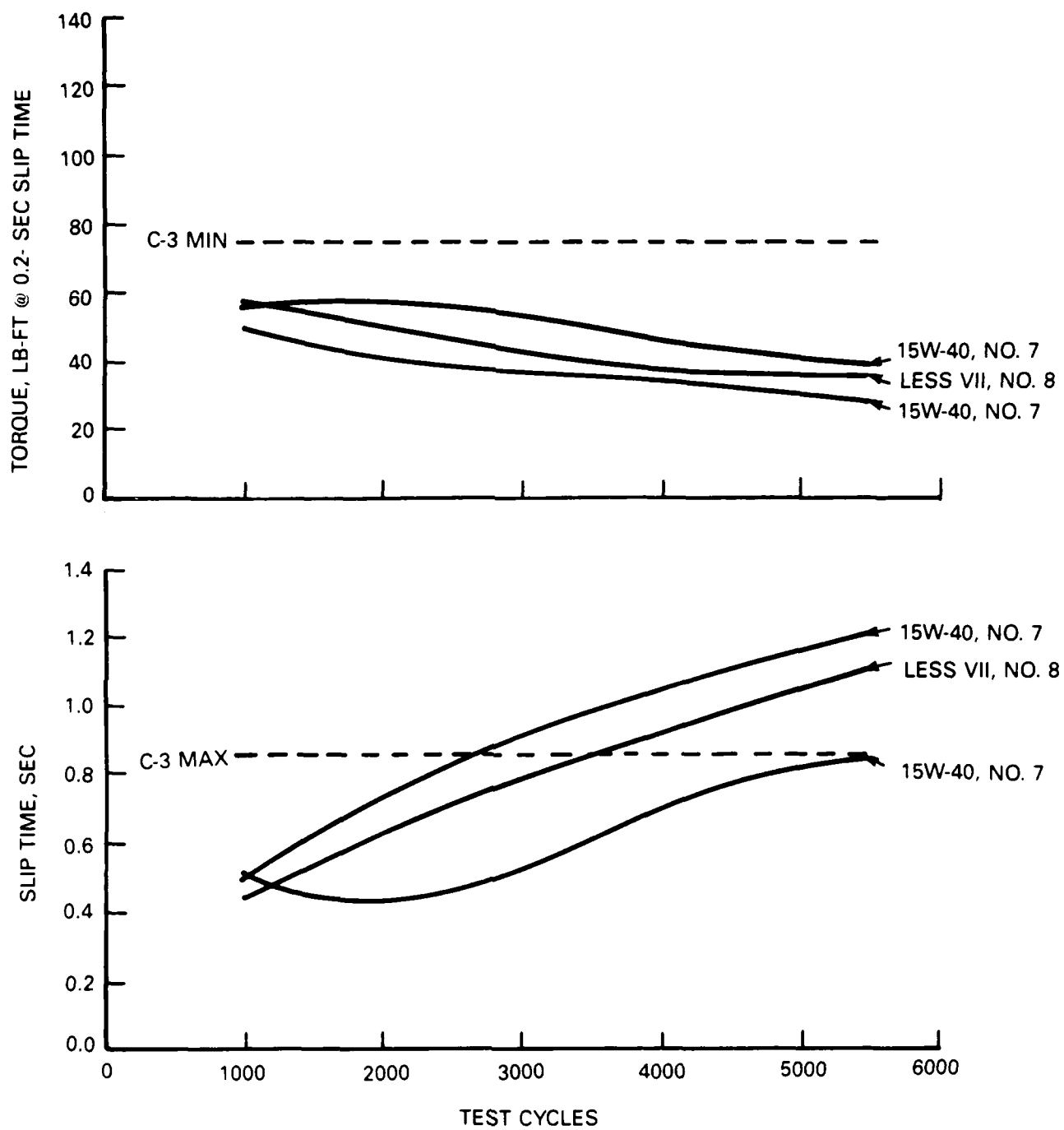


Figure 4. Effect of VI improver using SKW-167B material

TABLE 7. Friction Test Results of Modified C-3 Bronze
(SKW-167B) at Various Temperatures

Lube No.	Grade	Temp, °F(°C)	5500 Cycle Torque, 75 min	Slip time, 0.85 max	Torque Difference	Wear, in. (cm)	
						Steel	Bronze
1	C-3 Pass	235(113)	37	1.54	-5	0.0007 (0.1778)	0.0012 (0.3048)
1	C-3 Pass	325(163)	22	2.73	0	0.0014 (0.3556)	0.0019 (0.4826)
	Stopped at 1555 cycles						
3	10W	235(113)	49	1.21	-12	0.0009 (0.2286)	0.0012 (0.3048)
3	10W	250(121)	38	1.56	-19	0.0014 (0.3556)	0.0014 (0.3556)
3	10W	275(135)	28	1.83	-21	0.0011 (0.2794)	0.0005 (0.1270)
3	10W	300(149)	34	1.61	-19	0.0011 (0.2794)	0.0012 (0.3048)
			(28 min)	(1.90 max)			
3	10W	325(163)	25	2.57	-21	0.0013 (0.3302)	0.0011 (0.2794)
4	30	325(163)	57	1.63	-20	0.0011 (0.2794)	0.0011 (0.2794)
			(48 min)	(2.29 max)			
4	30	325(163)	15	2.40	-38	0.0006 (0.1524)	0.0004 (0.1016)
5	15W-40	325(163)	22	2.53	-37	0.0007 (0.1778)	0.0205 (5.207)*
5	15W-40	325(163)	30	1.85	-25	0.0010 (0.0254)	0.0008 (0.2032)
6	15W-40	325(163)	30	2.40	-15	0.0005 (0.1270)	0.0007 (0.1778)
	Stopped at 5005 cycles						
6	15W-40	325(163)	20	2.38	-15	0.0006 (0.1524)	0.0007 (0.1778)
	Stopped at 3982 cycles						
6	15W-40	325(163)	25	2.60	-10	0.0009 (0.2286)	0.0008 (0.2032)
7	15W-40	325(163)	80	0.98	-4	0.0010 (0.2540)	0.0016 (0.4064)
			(1.81 max)				
7	15W-40	325(163)	20	2.38	-26	0.0006 (0.1524)	0.0007 (0.1778)
			(2.50 max)				
9	15W-40	325(163)	23	2.25	-25	0.0011 (0.2794)	0.0007 (0.1778)

* Lube No. 5, grade 15W-40 had erratic high wear that could not be repeated.

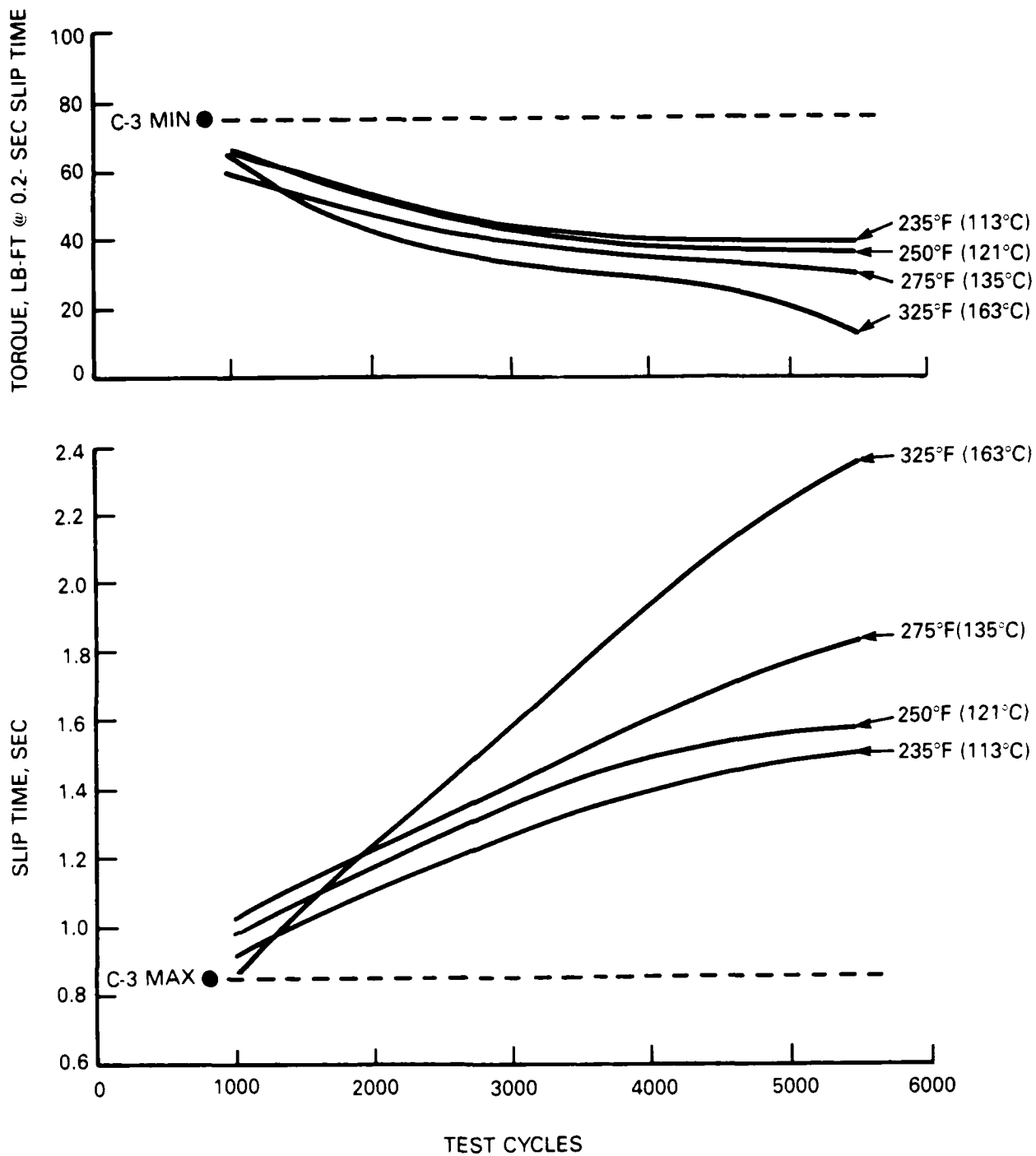


Figure 5. Effect of temperature on grade 10W - No. 3 using SKW-167B

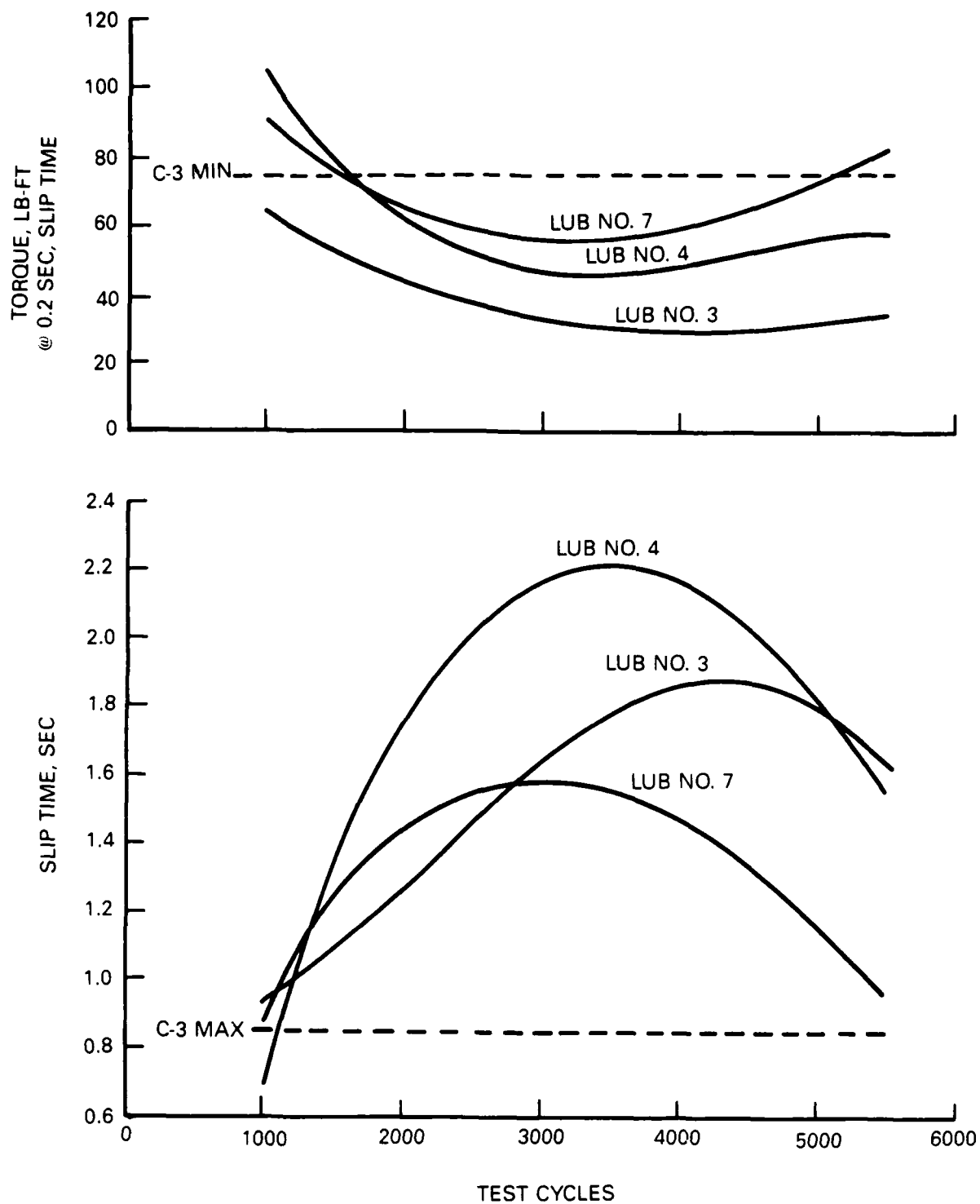


Figure 6. Lubricant parabolic effect

6 was collected from a different drum and tested in duplicate. The first friction test was stopped at 3982 cycles, and the second test was stopped at 3578 cycles. From these data, Lubricant No. 6 may have some field stopping problems at the higher transmission oil temperatures (300°F to 325°F) (149°C to 163°C). Also, Lubricant No. 5 had high wear at the 325°F (163°C) lubricant temperature, but the results could not be reproduced.

With the completion of the high-temperature tests, the load was increased from the standard C-3 flywheel kinetic energy of 13,800 ft-lb to 15,500 ft-lb, keeping all other operating conditions at standard C-3 conditions. Lubricant Nos. 3 through 9 were evaluated using the SKW-167B bronze friction material, and the data are shown in TABLE 8. The increased load resulted in more glazing on the majority of the bronze discs when compared to the standard C-3 flywheel kinetic energy load as indicated by the longer sliptimes and lower wear rates. As expected, the steel reaction plates and bronze friction discs with the least glazing had the most wear. Glazed bronze discs were analyzed with the electron microscope interfaced to the XRF analyzer to determine the composition of the glazed material. The glaze consisted primarily of sulfur and zinc, which probably came from the additive package.

Next, tests were conducted with the lubricant temperature increased to 325°F (163°C) and 15,500 ft-lb flywheel kinetic energy. Lubricant Nos. 1, 3, 4, 7, and 8 were evaluated. None of these lubricants could complete the required 5500 cycles due to inability to stop within the 2.5-second stopping time (TABLE 9).

The effect of apply pressure was also investigated. The SKW-167B bronze material was used with an apply pressure of 60 psi rather than the standard 120 psi pressure. For these tests, Lubricant Nos. 1, 3, and 6 were evaluated (TABLE 10). No apparent difference was observed between the lubricants. When compared with the previous data, the torque appeared to remain about the same, but the sliptime increased, as would be expected. Next, attempts to increase the apply pressure to 150 to 160 psi were made. However, 130 psi was the maximum pressure that could be attained. This 10-psi pressure increase was insufficient to provide a noticeable effect. To permit the rig to operate at the desired increased pressure would have required costly rig modification, which was beyond the scope of this project.

TABLE 8. Friction Test Results of Modified C-3 Bronze (SKW-167B) at 15,500 Ft-Lb Kinetic Energy and 235°F (113°C) Temperature

Lube No.	Grade ^a	5500 Cycle Torque, 75 min ^b	Sliptime, 0.85 max ^b	Torque Difference, 30 max ^b	Wear, in. (cm) ^c	
					Steel	Bronze
3	10	56 (38 min)	1.29 (1.59 max)	-7	0.0013 (0.3302)	0.0018 (0.4572)
3	10	26	2.72	-17	0.0007 (0.1778)	0.0008 (0.2032)
4	30	42 (30min)	1.49- (2.23 max)	-4	0.0011 (0.2794)	0.0016 (0.6096)
4	30	63	1.25	+21	0.0012 (0.3048)	0.0024 (0.6096)
5	15W-40	28	2.69	-16	0.0006 (0.1524)	0.0009 (0.2286)
6	15W-40	38	2.00 (2.47 max)	0	0.0005 (0.1270)	0.0010 (0.2540)
6	15W-40	23	3.00	-16	0.0007 (0.1778)	0.0009 (0.2286)
7	15W-40	68 (49 min)	1.11	+13	0.0016 (0.4064)	0.0034 (0.8636)
7	15W-40	17	2.65	-7	0.0007 (0.1778)	0.0007 (0.1778)
Stopped at 4896 cycles						
7	15W-40	64 (43 min)	1.31	+21	0.0010 (0.2540)	0.0020 (0.5080)
8	7 With- out VII	56	1.38	+6	0.0010 (0.0254)	0.0014 (0.3556)
8	7 With- out VII	55	1.43	+2	0.0012 (0.3048)	0.0017 (0.4318)
9	1W-40	53	1.23	+7	0.0014 (0.3556)	0.0028 (0.7112)

^a All MIL-L-2104D unless specified otherwise.

^b Values for Allison C-3 Friction Test using graphitic friction materials:

Minimum torque at 0.2-sec sliptime at 5500 cycles = 75 lb-ft

Maximum sliptime at 5500 cycles = 0.85 sec

Maximum difference in torque at 0.2-sec sliptime between 1500 and 5500 cycles = 30 lb-ft

^c Caterpillar TO-2 maximum average wear: 2-steel plates = 0.004 in.(1.016 cm)
1-bronze plate = 0.010 in. (2.54 cm)

TABLE 9. Friction Test Results of Modified C-3 Bronze (SKW-167B) at 15,500 Ft-Lb Kinetic Energy and 325°F (163°C) Temperature

Lube No.	Grade	5500 Cycle Torque, 75 min	Sliptime, 0.85 max	Torque Difference, 30 max	Wear, in (cm)	
					Steel	Bronze
1	C-3 Pass	22 Stopped at 1500 cycles	2.73	-31	0.0014 (0.3556)	0.0019 (0.4826)
3	10W	43 Stopped at 1500 cycles	2.42	--	0.0007 (0.1778)	0.0009 (0.2286)
4	30	21 Stopped at 1502 cycles	2.82	--	0.0009 (0.2286)	0.0008 (0.2032)
7	15W-40	27 Stopped at 2543 cycles	2.79	-9	0.0006 (0.1524)	0.0005 (0.1270)
8	7 With-out VII	25 Stopped at 2640 cycles	2.70	-6	0.0007 (0.1778)	0.0006 (0.1524)

TABLE 10. Modified C-3 Friction Test Using SKW-167B Bronze With 60 Psi Apply Pressure

Lube No.	Grade	5500 Cycle Torque, 75 min	Sliptime, 0.85 max	Torque Difference, 30 max	Wear, in (cm)	
					Steel	Bronze
1	C-3 Pass	23	2.49	+1	0.0010 (0.2540)	0.0008 (0.2032)
3	10W	17	2.49	-3	0.0006 (0.1524)	0.0004 (0.1016)
6	15W-40	17	2.50	-10	0.0011 (0.2794)	0.0006 (0.1524)

C. RM-1350 Bronze Friction Material

Lubricant Nos. 1, 3, and 6 were evaluated using the RM-1350 bronze friction material, and all other operating conditions were those of the standard C-3 friction test. All three lubricants had similar results, as shown in TABLE 11. However, these results were not as good as the results using the RM-1349 and SKW-167B bronze friction material. When the lubricant temperatures were increased to 325°F (163°C), Lubricant Nos. 1 and 3 could not complete the standard 5500 cycles because of too long a sliptime. Also, the torque decreased and the sliptime increased when compared to the standard 235°F (113°C) temperature, with increased glazing on the bronze friction discs. At this point, the testing was stopped because the results had the same trends but were not as good as the RM-1349 and SKW-167B bronze friction material.

TABLE 11. Modified C-3 Friction Retention Test Using RM-1350 Bronze

<u>Standard Lubricant Test Temperature at 235°F (113°C)</u>						
Lube No.	Grade	5500 Cycle Torque, 75 min	Sliptime, 0.85 max	Torque Difference, 30 max	Wear, in (cm)	
					Steel	Bronze
1	C-3 Pass	24	2.14	-8	0.0004 (0.3556)	0.0009 (0.2286)
3	10W	25	1.95	-23	0.0003 (0.0762)	0.0011 (0.2794)
6	15W-40	24	2.15	-10	0.0005 (0.1270)	0.0007 (0.1778)
<u>Lubricant Test Temperature at 325°F (163°C)</u>						
1	C-3 Pass	22 Stopped at 4500 cycles	1.97	-14	0.0009 (0.2286)	0.0013 (0.3302)
3	10W	13 Stopped at 4000 cycles	2.15(2.50)	-19	0.0013 (0.3302)	0.0009 (0.2286)
6	15W-40	19	2.50	-16	0.0003 (0.0762)	0.0008 (0.2032)
1	C-3 Pass	25	2.08	-25	0.0007 (0.1778)	0.0009 (0.2286)

D. Friction Material Effects

When comparing the three bronze friction materials using the C-3 pass reference lubricant, the best friction material in torque and sliptime performance was the RM-1349, followed by the SKW-167B and RM-1350. The representative test results are shown in Fig. 7. This also holds true for the grade 10W, 30, and 15W-40 lubricants (see Figs. 8 through 10). Although there are no friction material wear specifications for the DDA C-3 friction test, limits are established for the Caterpillar TO-2 friction test. The TO-2 wear limits have a maximum average for the two steel reaction plates of 0.004 in. (1.016 cm) and a maximum wear of 0.010 in. (2.54 cm) for the bronze friction disc. There was no high wear with the steel reaction plates. With the bronze friction disc, the RM-1349 shows the most wear but is well within the TO-2 requirements. The RM-1349 also has the best torque and sliptime performance. There is some problem with repeatability since the torque and sliptime data points produce a parabolic curve (Figs. 11 and 12). This effect appears unexpectedly and is usually not repeatable. The parabolic effect is probably caused by the additive package, which is partially deposited on the bronze disc as glaze. As a result, sliptime is increased and torque decreased. Then, when the conditions are right, the glaze is removed by the detergent, resulting in a decrease in sliptime and an increase in torque.

E. Correlation With DDA/TACOM Work

DDA conducted an evaluation for TACOM to qualify a representative selection of MIL-L-2104D, grade 15W-40 lubricants for use in the DDA CD-850 transmission. This work by DDA/TACOM was conducted with the DDA clutch durability machine using the braking mode and three-energy level steering modes. These tests used SKW-145E bronze material which is similar to the SKW-167B used in the BFLRF modified C-3 bronze friction test. As a result of this work, DDA approved MIL-L-2104D, grade 15W-40 lubricants for usage in the CD-850 transmissions and conditional approval for the XT-1410 both have clutch steering. In addition, DDA evaluated the results and ranked the lubricants as to performance.⁽¹³⁾ These same lubricants were evaluated in the BFLRF-modified C-3 bronze friction test. The tests were conducted with the SKW-167B bronze friction material at both the standard 235°F (113°C) lubricant temperature and at the increased lubricant temperature of 325°F (163°C). The results from these BFLRF tests were evaluated, rated, and ranked. As seen in TABLE 12 and Fig. 13, these tests resulted in the same order of performance ranking as the DDA CD-850 work.

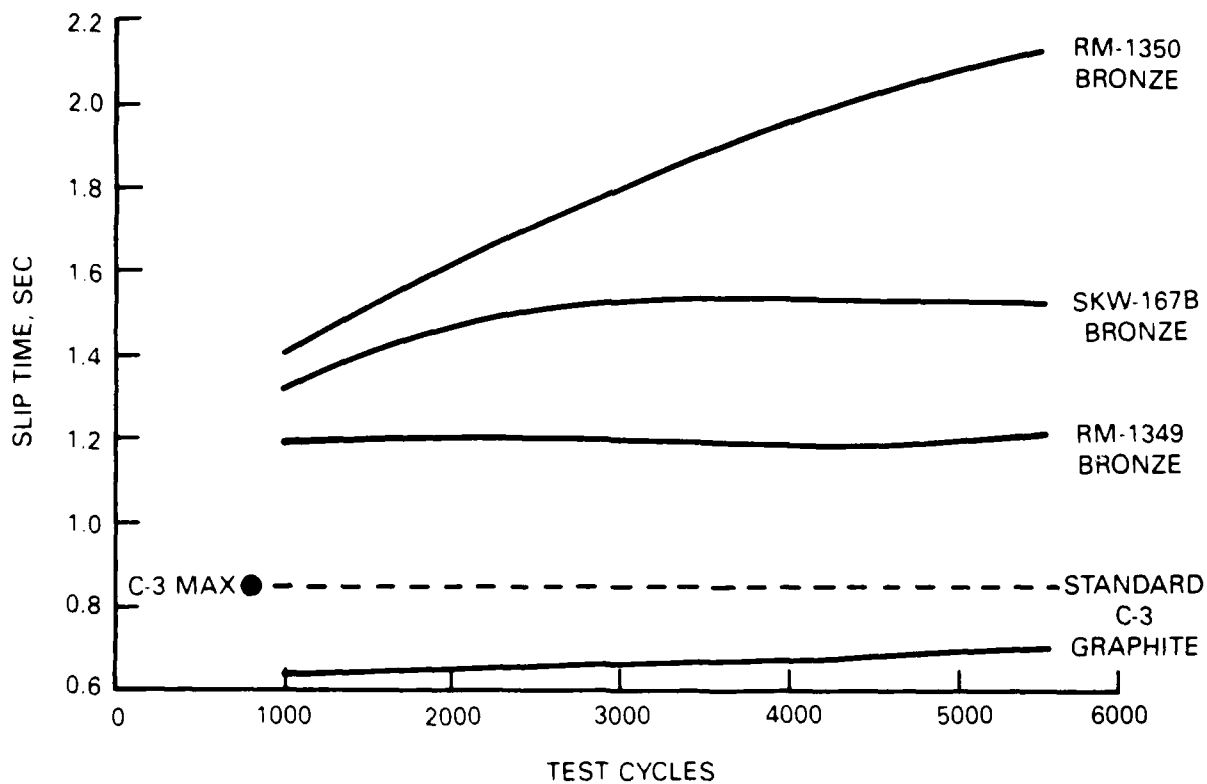
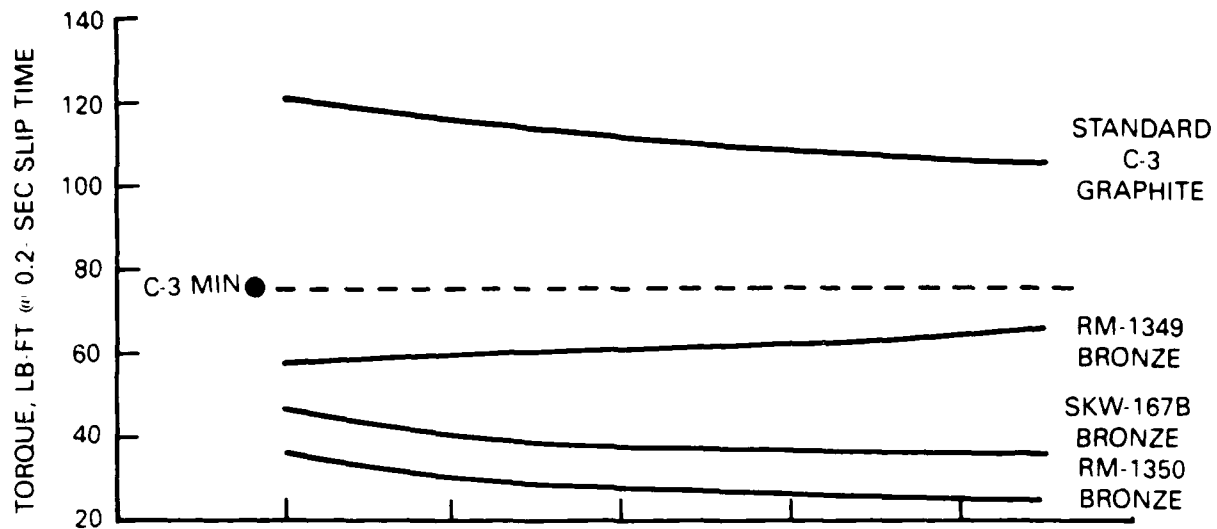


Figure 7. Material effects with C-3 pass oil - No. 1

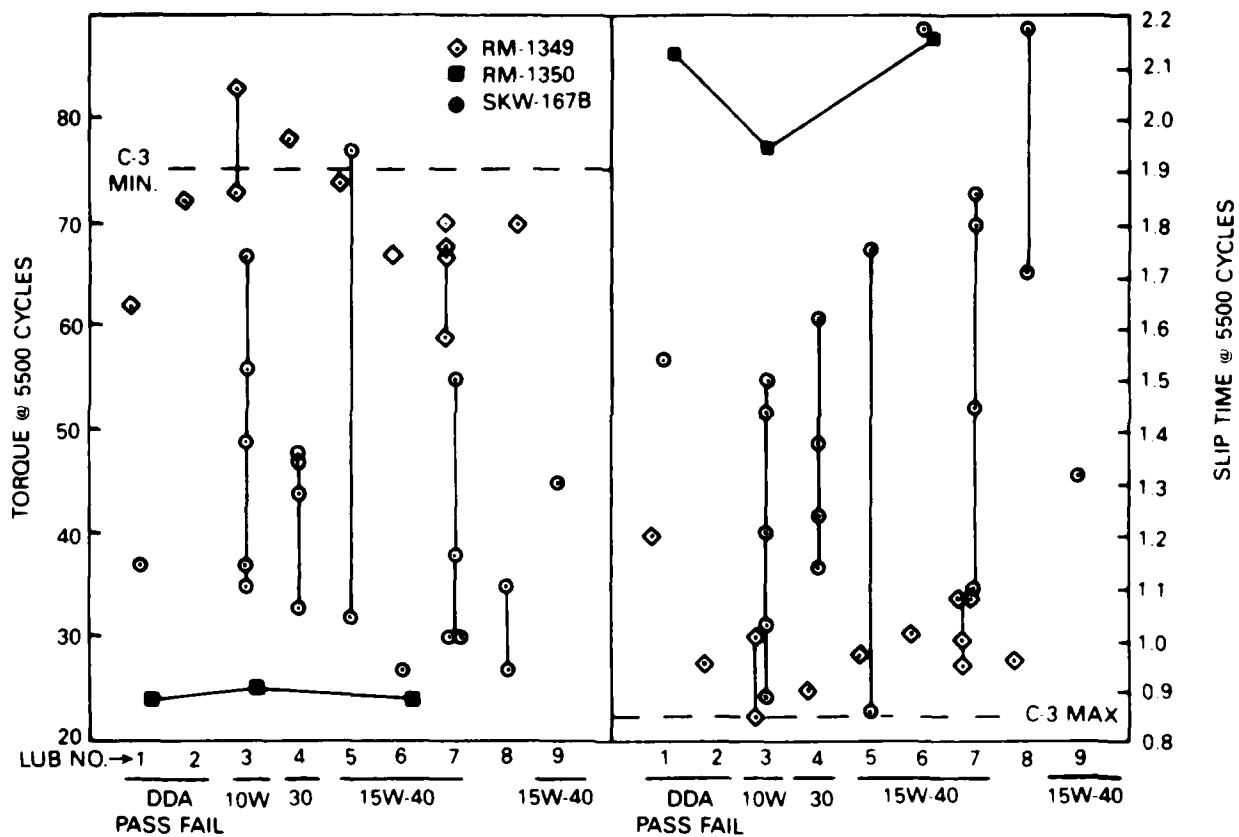


Figure 8. Modified C-3 bronze friction test standard conditions

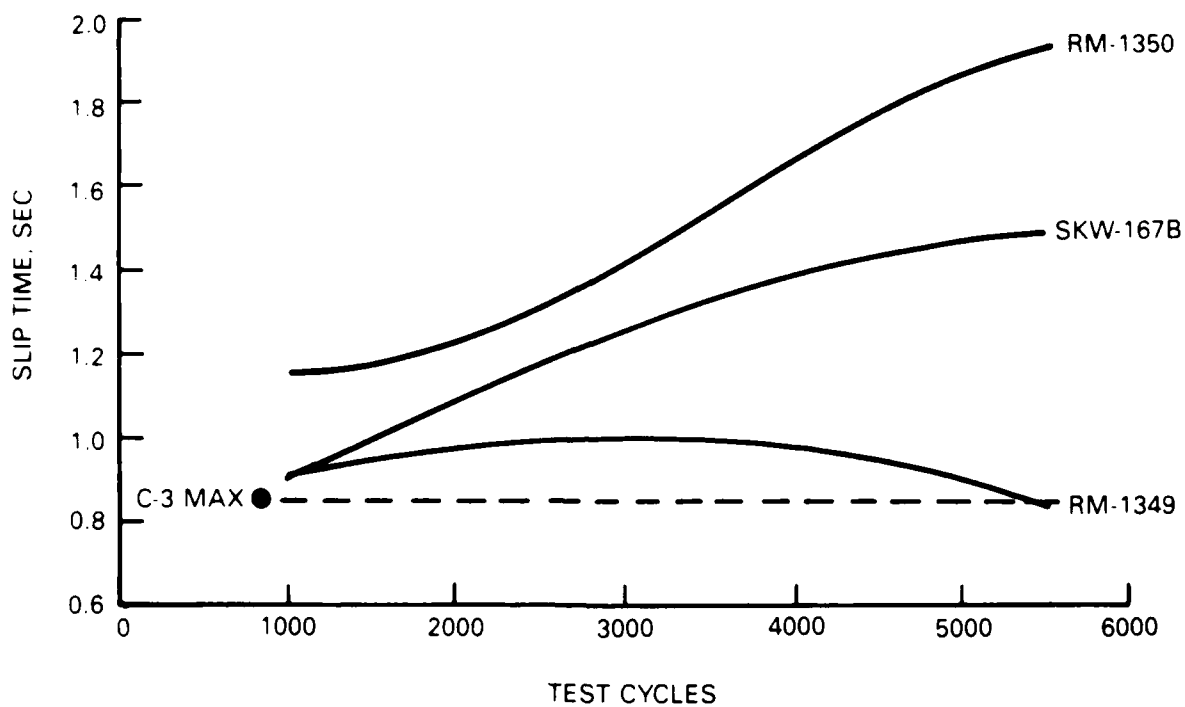
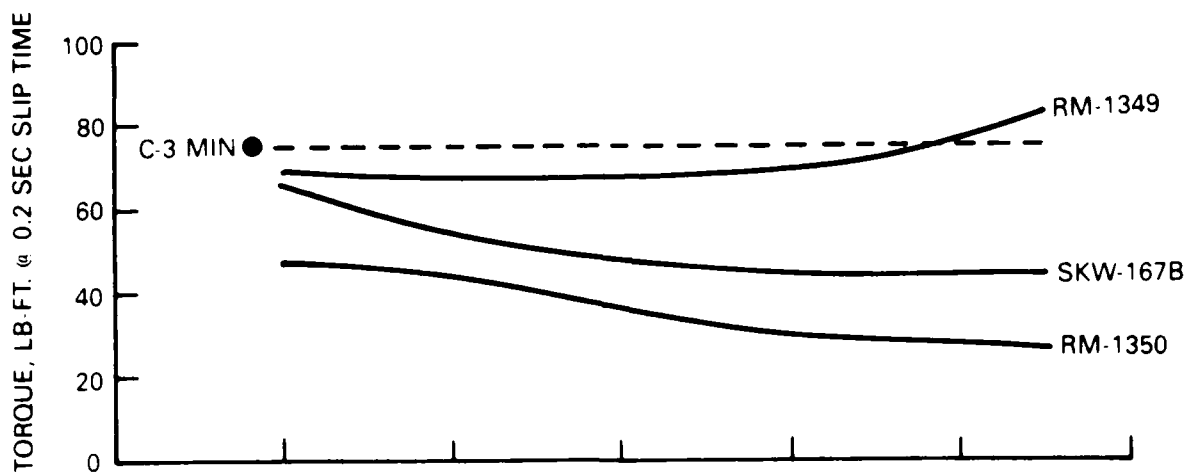


Figure 9. Effect of friction material on grade 10W - No. 3

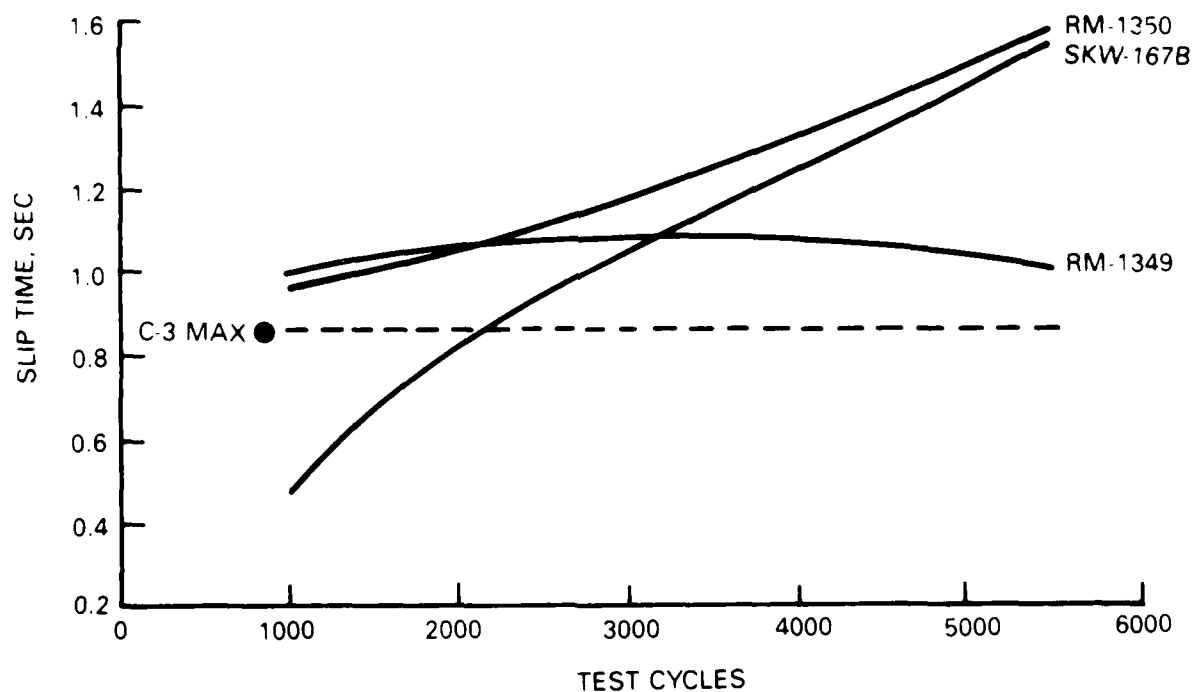
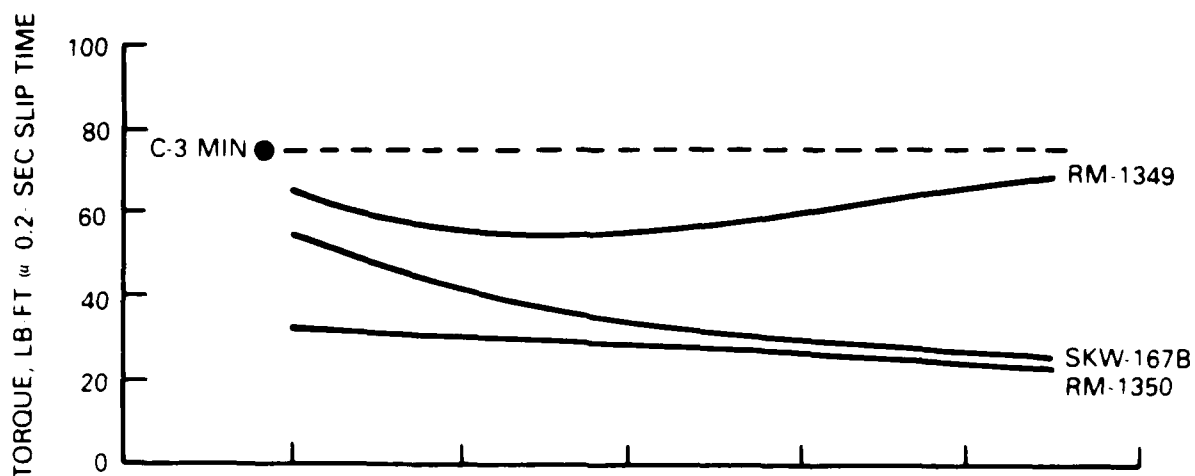


Figure 10. Effect of friction material on grade 15W-40 - No. 6

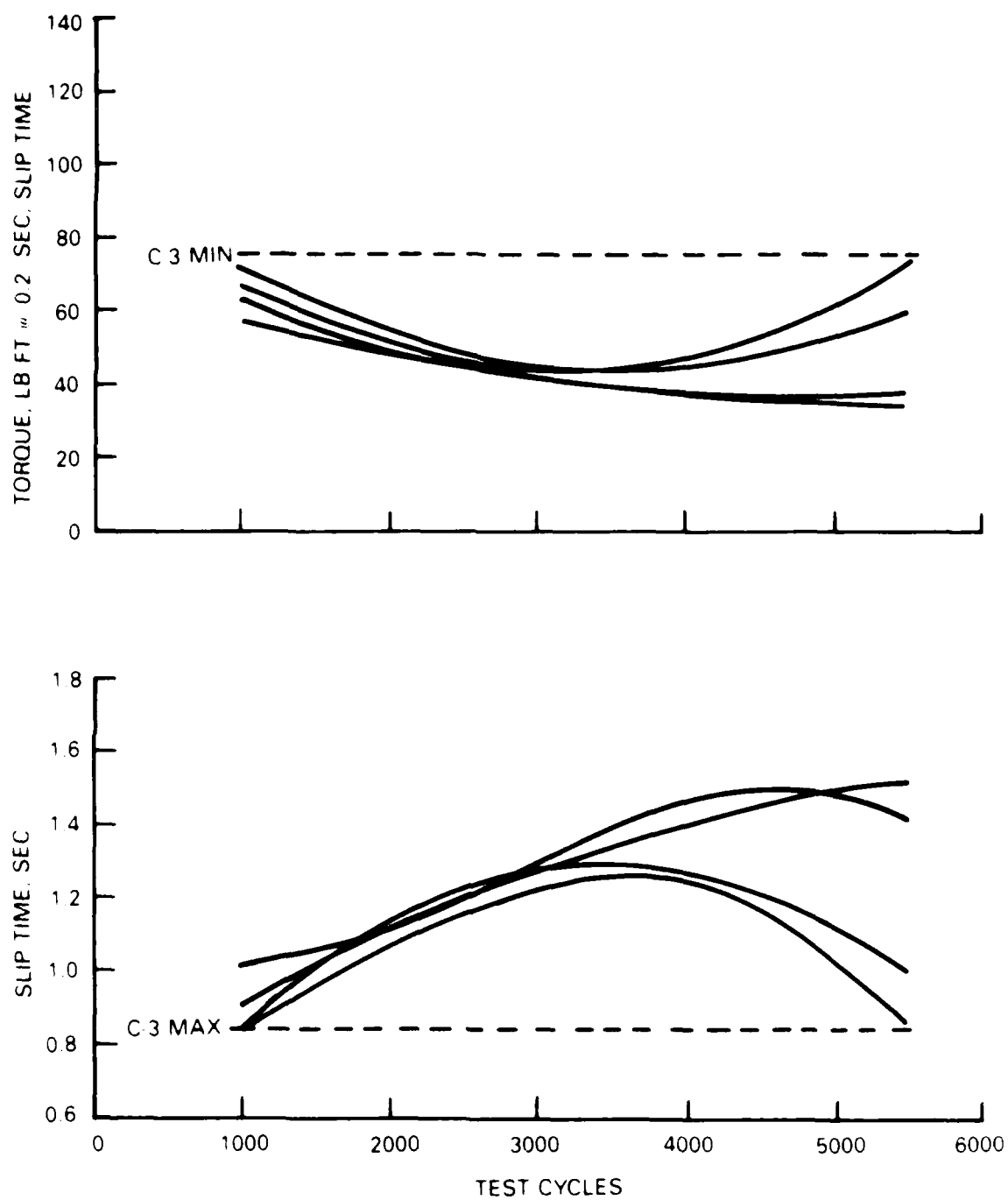


Figure 11. Repeatability with SKW-167B using grade 10W - No. 3 and standard conditions

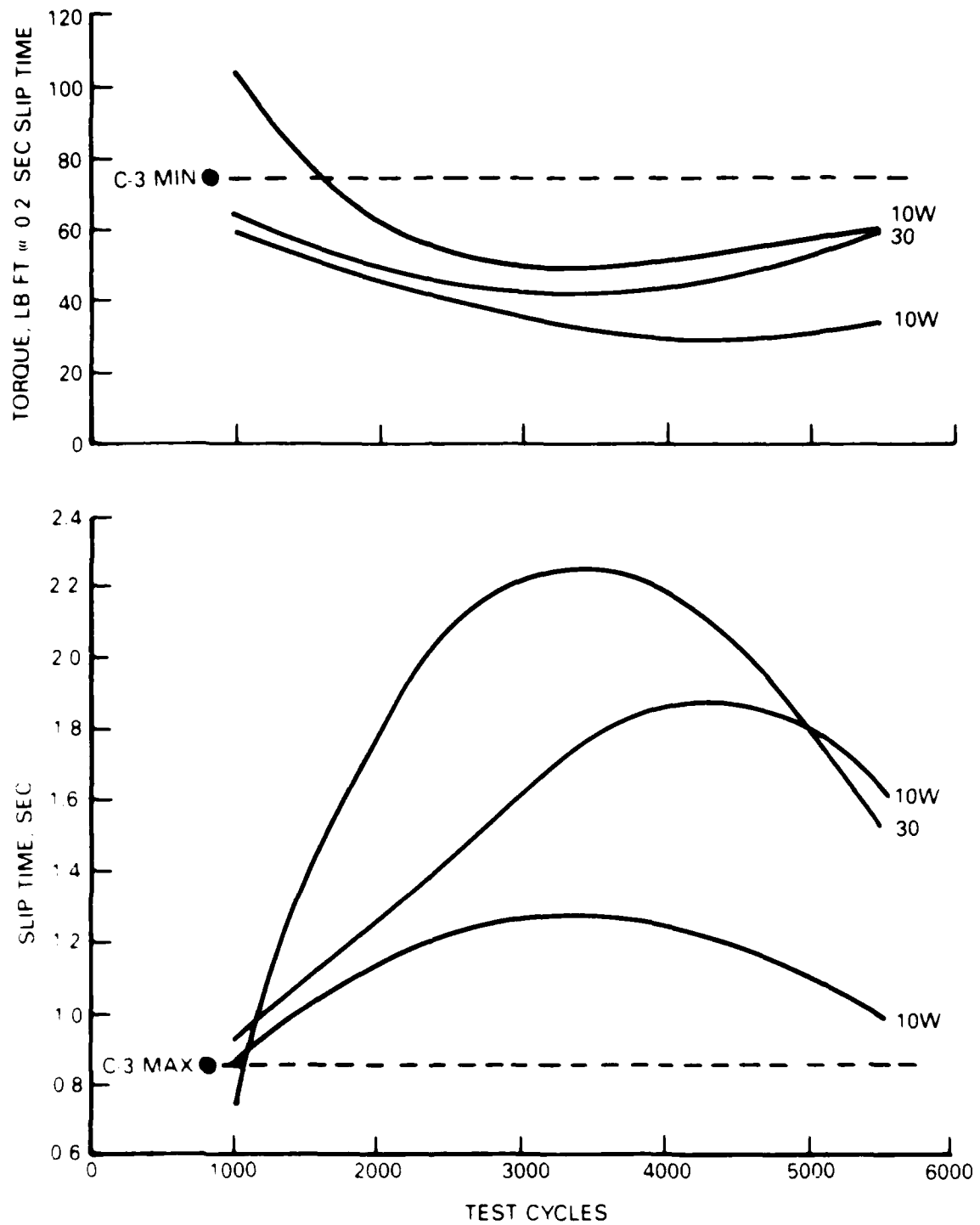


Figure 12. Parabolic effect (straight grade)

TABLE 12. Lubricant Evaluation Score Sheet

Properties	Modified C-3 Bronze			
	Grade 10W	Grade 15W-40		
	Lube No. 3	Lube No. 5	Lube No. 6	Lube No. 9
5500 Cycle Torque	3	4*	1	2
Sliptime, max	2	4	1	3
Torque Difference	3	4	2	1
Steel Wear	2	3	4	2
Bronze Wear	3	1	4	2
TOTAL	13	16	12	10

* 4 = Best Score.

Ranking (1 = Best)

BFLRF Mod. C-3	2	1	3	4
DDA CD-850 Test	2	1	3	4

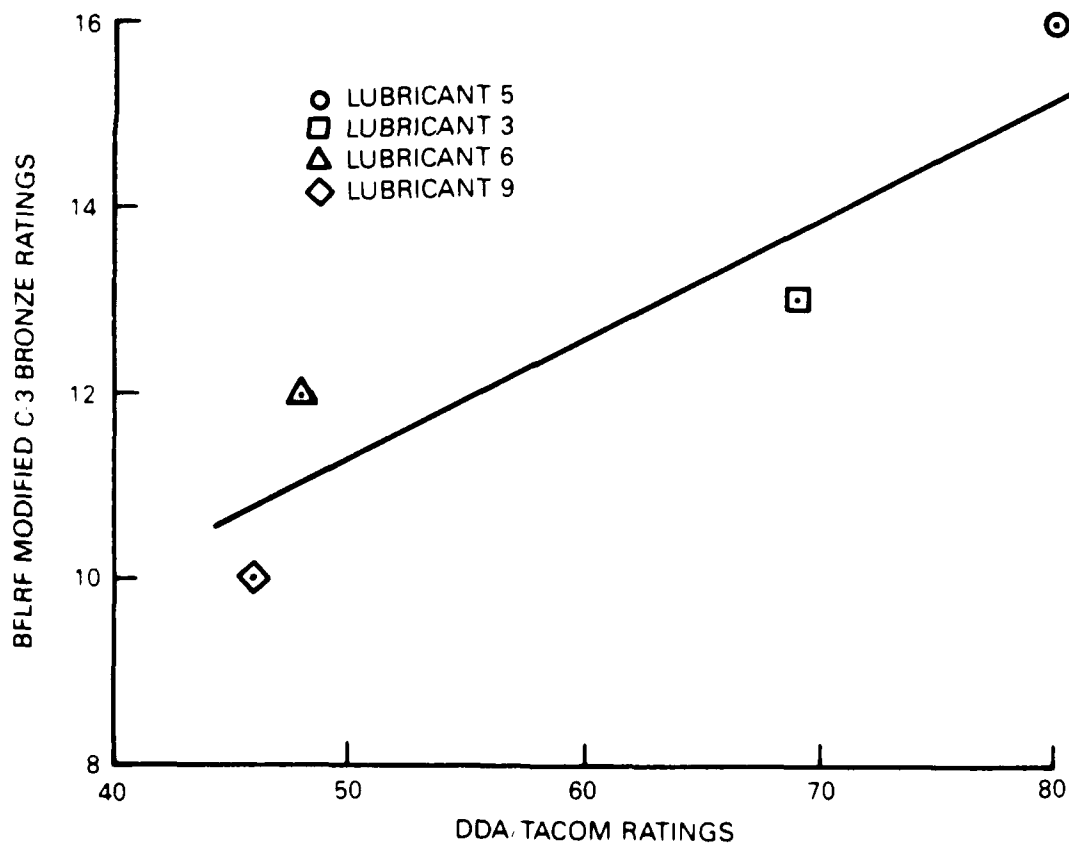


Figure 13. Modified C-3 bronze rankings versus DDA/TACOM rankings

VI. CONCLUSIONS

This work with RM-1349 bronze friction material appears to verify the actual past good field performance with the DDA CD-850 transmission. The results to date, when using the three bronze friction materials, show that:

- No lubricant, including the C-3 pass reference oil, using the three bronze materials met the DDA C-3 friction retention test requirements.
- Friction material performance rated best to worst was RM-1349, SKW-167B, and RM-1350.
- No substantial difference was observed among the lubricants in torque, sliptime, and wear when using the same friction material.
- The VI improver of a 15W-40 multigrade oil had no effect on torque, sliptime, or wear.
- As the lubricant temperature increased, the torque decreased and the sliptime increased, with no apparent change in wear.
- Some transmissions may perform sluggishly and or abruptly because shear and/or temperature may put the oil out of its viscosity range for that transmission.
- As the flywheel energy was increased, more glazing appeared on the bronze discs. The glazed material consisted primarily of sulfur and zinc, which probably came from the engine oil additive package.
- Some erratic high wear was experienced with all three bronze friction materials, but could not be reproduced.
- The bronze friction discs which exhibited wear had only slightly visible to no visible glazing.
- This work using modified C-3 friction tests ranked the MIL-L-2104D lubricants in the same order of performance as did the DDA CD-850 transmission friction bench tests, with which the 15W-40 lubricants were qualified for use by DDA.
- Overall the MIL-L-2104D, grade 15W-40 lubricants should operate satisfactorily in the majority of the present tactical automatic and powershift transmissions.

These bench test results and the field testing results (14) demonstrated that the 15W-40 lubricants will meet the frictional requirements of the DDA tactical automatic and powershift transmissions.

VII. RECOMMENDATIONS

Even though the DDA/TACOM results and the results from the BFLRF modified C-3 bronze friction tests appear to correlate, there is still some area of concern. The limited results with the bronze multipack using RM-1349 bronze material indicate that some work needs to be conducted in the multipack area. Also, the lubricant specification for preservative/operational engine oil, MIL-L-21260, is being revised and upgraded to the performance level of MIL-L-2104D. Previous experience has shown some MIL-L-21260 oils give unexpected wet-friction performance results with some bronze materials. Therefore, the new MIL-L-21260 grade 10W, 30 and 15W-40 lubricants should be evaluated in the modified C-3 bronze friction test with the addition of preservative zinc additive.

VIII. REFERENCES

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